

THE ECONOMICAL MICROBOLOMETER-BASED ENVIRONMENTAL RADIOMETER SATELLITE (EMBERSAT) DESIGNED FOR FOREST FIRE DETECTION AND MONITORING

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ABSTRACT

Thermal infrared imagery from several satellite instruments, such as the NOAA AVHRR and the NASA MODIS, is presently used to detect and map forest fires. But while these radiometers can identify fires they are designed and optimized for cloud detection, providing relatively low spatial resolution and quickly saturating even for small fires. Efforts to detect and monitor forest fires from space would benefit from the development of single-sensor satellites designed specifically for this purpose. With the advent of uncooled thermal detectors, and thus the absence of aggressive cooling, the possibility of developing small satellites for the purpose of fire detection and monitoring becomes practical and cost-effective. Thus is the case with the Economical Microbolometer Based Environmental Radiometer Satellite (EMBERSat) program. The objective of this program is to develop a single, prototype satellite that will provide multi-band thermal imagery with a spatial resolution of 250m and a dynamic range of 300-1000K. The thermal imaging payload has flight heritage in the Infrared Spectral Imaging Radiometer that flew aboard mission STS-85 and the spacecraft is a variant of the SimpleSat bus launched from the shuttle Columbia as part of STS-105. The EMBERSat program is a technology demonstration initiative with the eventual goal of providing high-resolution thermal imagery to both the scientific community and the public.

INTRODUCTION

Satellite meteorology contributes a wealth of infrared imagery that is useful in identifying and monitoring forest fires from space. But while there is a niche for these data in fire detection their utility is limited by instrument design goals emphasizing the detection of clouds rather than fires. Clouds tend to be larger in extent and less bright in the infrared than fires and thus this imagery is of relatively coarse spatial resolution for fire detection and even small fires can saturate pixels. Further, the flight programs that provide these data do not have the flexibility to adopt changes that would make these measurements more useful for fire monitoring. The reasons being that these programs are costly and emphasize the provision of general-purpose meteorological data with a minimum of risk. As a result, the goal of achieving innovation in replacement payloads becomes secondary to the goal of providing data continuity and the security of past radiometer designs, which include HgCdTe detectors cooled to below 100K. Thus, in addition to not being optimally configured for fire detection these instruments also include the nontrivial costs and complexities associated with aggressive cooling. With the advent of uncooled IR detector technology new and exciting opportunities emerge to meet the challenges of remote fire detection using single-sensor, small satellites designed specifically for this measurement.

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In developing small satellites for infrared earth remote sensing the importance of eliminating aggressive cooling of the payload cannot be overstated. Such cooling typically consumes large amounts of electrical power, which is a precious commodity onboard a spacecraft. Further, the cooling subsystem adds cost, complexity and risk to the satellite development. Another important consideration in the development of small satellites is the presence of moving components often necessary to image in two dimensions. Uncooled detectors are available in large format arrays (480x640 pixels) and provide simultaneous imaging in two dimensions. The extended format of the array can also be used to improve the SNR of the measurement through the use of frame-averaging techniques such as Time Delay and Integration. By realizing these advantages the size and cost of IR imagers are reduced making them well suited for small spacecraft with limited power production capabilities.

The primary mission of the EMBERSat program is to demonstrate the utility of uncooled detector technology for identifying and monitoring forest fires from space using small, single-sensor spacecraft. The enabling technology is an uncooled microbolometer array detector (UMAD) built by BAE Systems. The EMBERSat project has its origins in two previous NASA flight projects that include the Infrared Spectral Imaging Radiometer (ISIR) and SimpleSat. The ISIR instrument was the first IR imaging radiometer payload to include a UMAD array and is shown on the left in Figure 1 (Lancaster et al., 2003). SimpleSat is a low-cost spacecraft bus designed for small payload applications and is shown on the right in Figure 1. Both were shuttle Hitchhiker projects.

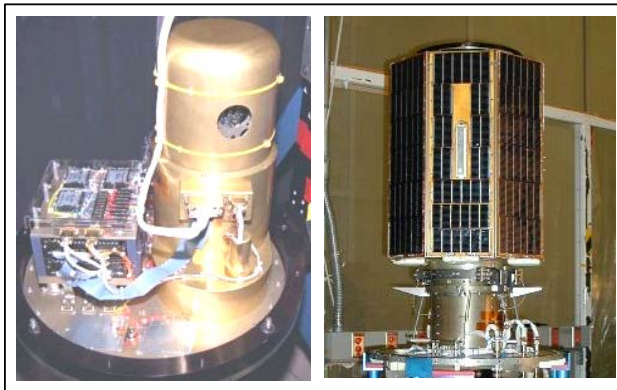


Figure 1: ISIR payload and SimpleSat spacecraft bus.

FIRE DETECTION METHODOLOGY

Forest fires appear bright in satellite imagery as a result of the enhanced blackbody emission they produce relative to cooler background regions. Thus to identify fires one searches the imagery for regions of anomalously high brightness temperature. The optimal portion of the infrared spectrum in which to conduct this search is the MWIR at a wavelength near 3.7 μ m. This wavelength corresponds to the color temperature of a fire at 800K and is centered within the atmospheric transmission window extending from 3.5 to 4 μ m. A channel near 11 μ m is used to provide context for what represents an anomalously high brightness temperature. This 11 μ m background channel is chosen based upon the color temperature of an object at 300K and the presence of an atmospheric transmission window. After calibration of the imagery a brightness temperature is calculated for each pixel in each of these spectral bands. The results of the background channel calculation are subtracted from those of the fire detection channel revealing pixels that contain the enhanced signature of a forest fire.

The level of spatial detail that is required to monitor forest fires from space depends upon the particular application. Data from existing meteorological satellites are currently utilized to assemble fire maps with a spatial resolution of about 1km. While this is sufficient for many applications there are others, such as potential operational uses, for which this spatial resolution is relatively coarse. Increasing the spatial resolution has associated costs, however, the primary ones being an increased data bandwidth or less frequent global coverage. Of these the latter is the most negotiable since two thirds of the earth is covered with water and not every fire needs to be viewed at the highest spatial resolution. Additionally, single-sensor spacecraft can be controlled for increased revisit times making higher spatial resolution practical.

The dynamic range of an imaging radiometer should be chosen so that saturation of the image is avoided. Current cloud radiometers typically saturate between 300-400K, which can occur even for small fires that do not fill the pixel field of view. To prevent saturation an upper limit of the dynamic range for a fire detection radiometer should be chosen around 1000K. The lower limit is selected to match typical background levels, which are at a temperature of about 300K. Historically, the choice of dynamic range

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has also been restricted by the availability of digitizing hardware. Until recently imaging radiometers were limited to between 8 and 12-bit resolution requiring that a compromise be struck between the thermal resolution and dynamic range.

PAYLOAD DESCRIPTION

EMBERSat is a technology demonstration program that combines an UMAD-based infrared camera with the SimpleSat spacecraft bus for the purpose of remote fire detection and monitoring. Of these two technologies it is the uncooled detector array and the associated camera payload that serve as the focus of the current work. The EMBERSat camera payload builds upon the flight heritage of the Infrared Spectral Imaging Radiometer, which flew aboard the shuttle Columbia in 1997. This ISIR instrument was developed as a prototype compact imager for small satellite missions and has the unique distinction of being the first satellite meteorology payload to incorporate a UMAD.

The camera payload of EMBERSat is configured to provide measurements in spectral bands centered at 3.7 μ m and 11 μ m. The former channel has a passband of 0.5 μ m and the latter 1 μ m. The spatial resolution of the imagery is 250m when acquired from shuttle orbit. The dynamic range of the camera covers scene temperatures of 300 to 1000K and 14-bit thermal resolution is achieved.

Shown in Figure 2 are the telescope and detector electronics of the EMBERSat pushbroom imaging payload. This camera provides a cross track field of view of 15 degrees and 240x320-pixel imagery at a maximum rate of 60 frames per second. Channel selection is accomplished through the use of a spectral strip filter array assembled inside the UMAD package. The filter is oriented so that each portion of the ground track is sampled sequentially in the different spectral channels as the spacecraft advances in its orbit. This approach to spectral selection eliminates the need for a filter wheel, which would otherwise draw precious electrical power.

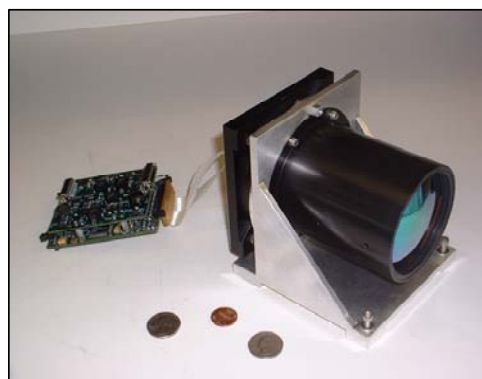


Figure 2. EMBERSat detector readout electronics and telescope

RADIOMETRIC PERFORMANCE

The EMBERSat payload is built upon the flight heritage of the ISIR shuttle experiment, from which a sample of data is shown in Figure 3. Also included for comparison in Figure 3 are measurements acquired during a coordinated under-flight by the MODIS Airborne Simulator (MAS). The Moderate Resolution Imaging Spectroradiometer (MODIS) payload currently supplies much of the imagery used in remote fire detection. The data displayed in Figure 3 are used to glean an NEDT estimate of 300mK (294K scene) for the 11 μ m channel of ISIR and a radiometric precision of approximately 100mK for the identical MAS channel. It is important to note, however, that current uncooled detectors offer an approximate threefold improvement in radiometric performance over these early ISIR measurements. This has been confirmed through measurements of the EMBERSat detector array. Hence, the thermal precision of the 11 μ m background channel of EMBERSat will rival that of the MODIS payload.

The fire detection channel of EMBERSat is less sensitive to low temperatures than the background channel for a variety of reasons. This does not pose a difficulty, however, since fires supply ample radiation due to their high temperatures. Measurements of the fire detection channel of EMBERSat reveal an achieved NEDT of 16K for a scene temperature of 300K. This is sufficient to detect a 4m² fire burning at an average temperature of 500K against a 300K background. Larger fires can be monitored with greater thermal resolution since the NEDT improves with increasing scene temperature. For example, the same fire would be measured with a precision better than 0.1K if it filled the entirety of the 250m pixel footprint. This thermal resolution matches the precision limit defined by the background measurement.

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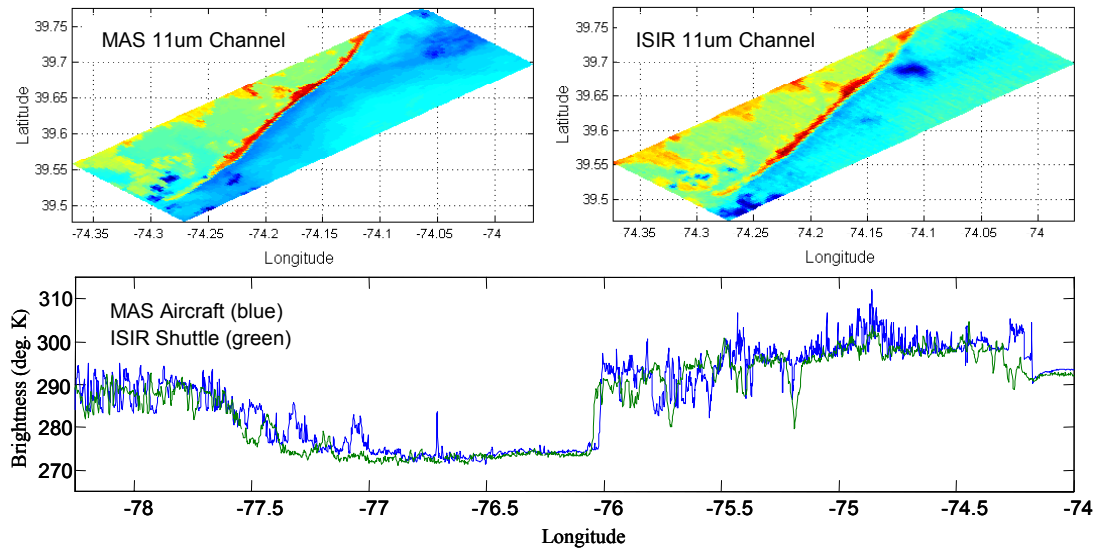


Figure 3: Comparison of imagery from the Infrared Spectral Imaging Radiometer that used an early prototype UMAD with MAS aircraft imagery commonly used in fire detection and monitoring.

DEVELOPMENT

The EMBERSat program operates under a development paradigm wherein undergraduate institutions build single-sensor satellites using the mature designs of previous NASA flight programs. The primary difficulty in developing satellites at the university level is that students and faculty typically have no experience doing so. The EMBERSat program fills this void by providing the flight designs, heritage and management experience required to make the program a success. University partners participate largely as technicians in this development. While unconventional this approach makes small satellite development accessible to even those institutions with no spaceflight infrastructure. All that is required on their part is a competence in science and engineering, an eagerness to accomplish something exciting and a willingness to follow instructions.

The EMBERSat program is designed for a budget of less than \$1M, which is much less than typical university-class satellites. There are several keys to achieving this budget. The first is to utilize existing flight designs. The second is to limit the program scope to one of technology demonstration requiring only a limited duration flight and providing for the exclusive use of commercial technologies. The third is to limit management to those engineers with direct experience developing either the spacecraft bus or the payload. By adopting these cost-saving measures widespread opportunity is created for educational institutions to participate in satellite development.

SUMMARY

With the advent of uncooled IR detector technology new and exciting opportunities emerge for the development of single-sensor satellites. EMBERSat is one such satellite designed to demonstrate the utility of using uncooled microbolometer array detectors for identifying and monitoring forest fires from space. The included UMAD technology is used to monitor fires with a spatial resolution of 250m, a dynamic range of 300-1000K and 14-bit thermal resolution. EMBERSat is being developed at the university level and provides undergraduate students with an opportunity be part of a satellite program that is both useful to the scientific community and capturing of the public's imagination.

REFERENCES

Lancaster, R.S., J.D. Spinhirne and K.F. Manizade, Combined infrared stereo and laser ranging cloud measurements from shuttle mission STS-85, J. Atmos. Ocean. Tech., 20, 67-78, 2003.